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METHODS OF APPROXIMATE COMPUTATION OF HUMAN ENDURANCE IN HIGH AND LOW TEMPERATURE ENVIRONMENTS

V.I. Krichagin

The problem of maintaining capacity for work of personnel under unfavorable exterior microclimatic conditions is beginning to acquire importance among the many problems of medically safeguarding the combat training activity of troops.

First, this is connected with the fact that as military technology (as well as defense installations) becomes more complex, persons in charge become increasingly isolated from the environment. On the agenda has been put the problem of standardizing living conditions in the working accommodations of aircraft and submarine crews, etc., the atmosphere and climate of which basically created artificially by technical means, although they do of course depend on external conditions to some extent. It is well-known that the maintenance of comfortable levels of temperature, humidity, and atmospheric composition is a technically solvable problem. However, air-conditioning demands large expenditures of energy and increases the weight and size of objects. Therefore, in most defense structures, especially in mobile combat systems, one need not figure on providing a comfortable microclimate in the wide sense of this term, but at certain periods it is entirely probable and unavoidable that even unfavorable temperature and humidity conditions will have to be permitted.

Normalization of the allowable limits of a particular unfavorable or undesirable combination of temperature and humidity is necessary, since severe breech of these limits have a negative effect on the working and fighting ability, as well as the health, of the personnel carrying out a combat mission.

When determining the degree of allowable deviation from a comfortable microclimate in a particular structure, it is necessary to take into account the character and intensity of the task being carried out by military personnel at the given phase of combat task: therefore it is not possible to give a general procedure for establishing allowable air temperature and humidity levels for all items of military technology and defense structures. However, it is possible to formulate general points of departure which may be used as guides to work out tactical and technical assignments for life support systems, to evaluate habitability conditions in existing and projected experimental military technology, to analyze climatic conditions of a particular proposed theater of military operations, etc. The secriteria should be a definite set of physiological indeces characterizing the different stages of effort of the defense reactions of the body to a worsening or an extreme increase in heat output and the correlated connections that have already been scientifically established between the meteorological characteristics of the environment of habitation and the response of the body to this environment.

Numerous scientific articles have been written on the problems of the protection of people from heat and cold and the study of human tolerance of high and low temperatures. Various systems of all-inclusive indexes, formulas, nomograms, etc. have been suggested. But occasionally it has sometimes been difficult for the

hygienist or the engineer to make any sense out of all the details about the various concepts that have been presented by various schools of scientific thought. Thus, as yet rules have not been delineated for the application of comfort, operational, equivalent, radiation and other temperatures intended for evaluation of influence of the complex of external environmental conditions on the human organism. These indexes allow a rather close determination of the so-called heat comfort zone but are not very useful for evaluating the weight of a particular uncomfortable conditions and determining the allowable time period man can remain in these conditions. Taking into account that in the practical work of evaluating off the shelf items (or comparing requirements for planned items) we most often have to deal with rather crude estimates, we have set ourselves a goal of compiling correlated outlines containing a set of initial data for solving problems occurring in daily practice. In order to do this, we compiled, analyzed, processed, partially recalculated and converted data from the articles on the subject that were available to us. The results are listed in the following composite tables and graphs.

Table 1 shows the whole range of thermal activity of the external environment conditionally subdivided into a series of degrees of discomforts. These degrees of discomforts are listed according to a scale of subjected heat sensors distributed throughoutthe environment by physiologists and hygienists, these are characteristics of the thermal state of the organism to a known extent. The indicators are calculated for a man weighing 65 kilograms and having a body surface area of 1.6 m^2.

Points 1-9 give data established by instruments in hygienic research or indicators by means of which it is possible to evaluate the degree of thermal activity of a environment in an organism under studied. Points 11-13, while explaining the absence in scientific literature of sufficient and concrete values, nevertheless rather carefully gives a basis for estimating the norms for the problem of the allowable time man may remain in a given environment in objects at varying degrees of thermal load. Thus for example, if an insignificant reduction in the accuracy of work being carried out by a man and a 20% loss in labor producitivity is allowable in his working conditions,then in the given object a calculation of the microclimate on discomfort of the first degree is allowable, etc. It should be pointed out that the table has been worked out to be applied to research objects in a state of rest or performing relative light physical work (thermal production up to 150 kcal/hr.).

Thus a summary of the data given in Table 1 for the results of physiological research of heating exchange indicators makes it possible to evaluate the intensity of environmental effects on human habitability. This evaluation is given in large discomfort categories I, II, and III degrees which are convenient for establishing norms. The implications will become clear in point 9-13 of the same table. In addition, the table contains a number of general indicators, such as arithmetic average temperatures of the body and skin, change in latent heat of the organisms and others which may be proposed as a basis for thermal technical calculations for protective means, air-conditioning period of endurance, etc. Due the multitude of criteria contained in this and other tables, it is possible to give a detailed explanation of the significance of each one of them or to give examples of their use within the scope of this article. For this reason, it turned out to be impossible to corroborate numerical values with references to their sources from which they are taken, since each value is a comparison of data of several other authors, and in many cases are only now being verified in current

scientific research. For a basis in compiling the tables, we used works by Soviet hygienist I.I. Bobrov, M.F. Galanin, G. Kh Shakhbazyan, N.K. Vitte, V.S. Freyclyn and other researchers who have been published abroad (Winslow, Herrington, Newburg, Barton, Webb and others).

TABLE I

Indicators for an Objective Evaluation of Human Thermal States

Thermal State and Thermal Sensitivity

Point Indicators Discomfort Third State (very hot) Discomfort Second Stage (hot) Discomfort First State (warm) Comfort

Discomfort First Stage (cool) Discomfort Second Stage (cold) Discomfort Third Stage (very cold)

1. Body temperatures (rectal) in °C/ Gradually increases more than 0.3° per hour/ About 37.6-37.8 / 37.2-37.6 / 37.2±0.4 varying not more than 0.2°/ per hour / Decrease to 36° at a rate greater than 0.2° per hour/ 35.5±0.5 / Lower than 35°

2. Armpit temperature in °C / not characteristic / not characteristic/ 36.6-37 / 36.5±0.4 varying not more than 0.2° per hour / on the lower borders / of comforts / lower than 36 / lower than 35

3. Average skin temperatures in °C[1] / more than 36.6°/ 36±0.6 / 34.9±0.7 / 33.2±1 / 31.1±1 / 29.1±1 / lower than 28.1 / Average body temperatures[2] / higher than 37.5 (specific endurance is at 38.2) / 37.2±0.3 / 36.6±0.3 / 35.8±0.5 / 34.9±0.5 / 33.6±0.7 / under 33

4. Difference between torso temp. & extremities / (feet and wrists) in °C/ lacking or inverse / 1° or less; higher at ft than at the wrists / 1.8±0.7 / 3±0.5 / 5±1.5 / from 6.5 to 15 / temp. gradually falls

5. Temp. & Humidity of subclose air around the torso[3]/ zone V/ zone IV/ zone III / zone II / zone I / under 26° / under 26°

6. Water loss in grams per hour / 500-2000, mostly of perspiration drips off/ 250-500, negligible fraction of perspiration drips off / 60-250, perspiration does not drip/ 50±10 / under 40 / insufficiently studied; not characteristic/ insufficiently studied , not characteristic

7. Changes of latent heat in the organism in kcals[2] (base: level of average comfortable temperatures)/ over 80 (a specific endurance around 120)/ up to +80 / up to +50 / ±25 / down to -80 / -160 / more than 160 (endurance limit 180-200)

8. External indicators / acute reddening of the skin, swelling of the veins on the face and extremeties, profuse perspiration/ reddening of the skin, swelling of veins of the extremeties, much perspiration/ light reddening of the skin, surface vein become visible at the extremeties, perspiration in certain areas of the body/ not perspiration / cutaneous blood pales; spasm of surface vein and capillary network/ light question of the skin and mucilaginous part, periodic shivering/ question of the skinand mucilaginous part, shivering

9. Physiological displacement (vegetative reaction)/ increase of exchange by 15% and more, pulse increases more than 15 strokes a min (danger level is 140 strokes a min)/ pulse increasesup to 15 strokes a min / none / none / none / 10-15% more heat is produced (Pulse increases up to 15 times a min) / short-term (2-3 hrs) increase in heat produced up to 300 kcal/hr; pulse increases up to 120 times a min

10. General characteristics of the state of thermal regulation/ sharp tension in the mechanisms for the increase of heat yield; danger of compensation failure / strong tension of the mechanism for increasing giving off of heat (complete compensation)/ weak tension of the mechanisms for increasing the yielding of heat/ physiological equilibrium / light tension of the mechanisms for maintaining heat / strong tension of the mechanisms for maintaining heat/ sharp tension of the mechanism for maintaining heat; danger of compensation failure

11. Reduction in labor productivity in % / up to 50% and more after 1/2-1 hr/ up to 50% and higher in 3-4 hrs / up to 10-20 after 6-8 hrs/ none up to 10-20 in 6-8 hrs. / up to 30-50 after four hours / up to 50% and more after 1/2-1 hr.

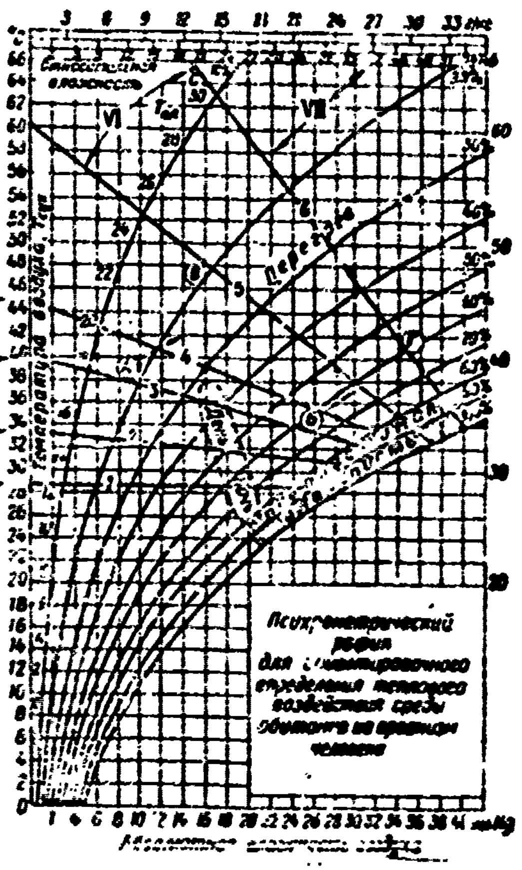
12. Reduction in reliability of performing exact operations/ operations possible with great will power / substantial / neglegible / none / negligible substantial / operation possible with great will power

13. Limit of endurance for performing skilled work / up to 30 minutes/ four hours / 12 hours / unlimited / 12 hours / 4 hours / up to 30 minutes

FOOTNOTES:

1) Method and measuring diagram: see V. Ramzayev; R.F. Afanas'yea; V.I. Krachagin, L.B. Kazantsev
2) Method of determination of formula: see Barton and Evbolm; for the measurement of thermal retention: Blokley and Webb.
3) See graph

The graph below is designed to predict roughly the degree of effect of high temperature conditions on man. The graph is constructed as follows: air temperature as measured by a dry thermometer is laid out along the vertical axis in isochrometric form; the partial perssure of water vapor in air is laid out along the horizontal axis in millimeters of mercury, millibars of g/kg), and the fan-like lines denote relative humidity of the air in percent. The straight lines in bold print numbered 1-6 are made by the combinations of temperatures and humidity which according to data from Winslow, Herrington and other authors, characterize identical states of thermal regulations of the organisms and at the same time approximately correspond to the transition of one thermal state to another. The graph was tested according to the data of various researchers (A.A. Putilova, V.S. Freydlin, G. Kh Shakhbazyan, N.A. Vitte, Motuoka and others) and the graph was also used in continuous experimental operations, thereby establishing that the line and the zones included between them corresponds well with man's subjective fields and makes possible an objective evaluation of comfort or the degree of discomfort of a given external environment. Naturally one graph like this cannot encompass all conceivable combinations of factors in a given environment (wind, radiation, type of clothing, etc.). Therefore, we prepared the graph for application to so-called zero conditions: for naked people in a state of relative rest or performing light work producing up to 150 kcals/hr of heat), in the absence of radiation and wind. Since a subclosed layer of air immediately surrounds a dressed person, the graph is useful in the evaluation of thermal sensitivity to temperature and humidity of the latter.



ABSOLUTE HUMIDITY

1 - border between states and comfort and cool for a lightly dressed person at rest;
2 - border between comfort and warm for an undressed or lightly dressed person;
3 - border between war and hot; 4 - border between hot and very hot; 5 - upper limit where it is possible to maintain a stable body temperature by means of wind, a fan or forcing air under the clothers; 6 - the limit when an air flow or forcing air under the clother does not slow down an increase in body temperature and only worsens the feeling of discomfort. Body temperature is 1-1.2° per hour (a working man has a higher rate of increase).

I. cool zone (for an undressed person at rest), discomfort of the first degree;
II. comfort zone
III. warm zone, discomfort of the first degree;
IV. hot zone, discomfort of the second degree;
V. very hot zone, discomfort of the third degree where without ventilation a slow overheating is possible;
VI. zone of inevitable overheating with the rate of temperature increase being 0.2-1.2° per hour;
VII. zone of rapid overheating guaranteeing a survival time of 1-2 hours or less

the calibration from -2 to +30 ranged along the relative humidity line for 10% denotes the temperature of a wet temperature at this humidity.
If for example, one connects the straight line of the calibrations for 20 with the intersecting point on the horizontal axis for the dry thermometer temperature +20 and the line 100 for humidity, one obtains the graphic value of the temperature of a wet thermometer of all intermediate values of relative humidity.

When using the graph in other cases, it is necessary to make the following additions.

1. At temperatures below 27° for the thermal state of man, some sort of clothing is provided; in this case for an objective evaluation of thermal sensitivity it is nece sary to draw in on the graph the temperature and humidity of subclosing air and not external air (automatically taking into account radiation and wind).

2. At temperatures above 27° for light clothing, the difference between the microclimate and the subclosing air can be neglected and the effect of the environment can be evaluated directly by temperature and humidity indicators with relatively small degree of error. This is explained by the fact that at these temperature, the greatest amount of heat given off occurs through the evaporation of perspiration which largely depends on the ability of the environment to evaporate. Ordinary light clothing however, as our research shows, lowers the efficiency of evaporation if there is no wind by 10 to 15%, and if there is a wind as a rule it barely lowers it at all. In case analysis of subjective sensitivity is necessary for persons dressed in specially provided clothing which is inappropriate for the season of the year, it is of course necessary to draw parameters on the graph for subclosing air.

3. When the air temperature and that of the protective environment is more than $\pm 5°$ it is necessary to take into account the additional flow or yield of heat by radiation and to make corrections for it (see table 2, subdivision A, point 6, Subdivision B, point 2). In addition, the graph delimits the zone of unallowable high air humidity. According to datafrom Robinson, Turrel and other researchers, the efficiency of evaporation for dressed persons begins to be reduced at humidity level above 60%; a particularly sharp reduction is noticed when the humidity increases above 80%. Taking into account the difficulty of reducing air humidity down to 60% which is required for general hygiene norms and the generally ignored resulting norm, we consider it necessary to emphasize an absolute unreliability on our graph of humidity above 80%, although formally these are degrees I and II of discomforts. Many researchers have noted that heat given off evaporation in these conditions due to possible condensation of moistures in the clothing is of low efficiency.

From the above and explanations presented with the graph, it is not difficult to explain the order of their use. Thus for example, conditions denoted by the letter A correspond to a temperature of 39.5° and relative humidity of about 18% (absolute humidity 9 millimeters of mercury or 12 emb of 8 g/kg) these conditions being given in zone IV, i.e. they are hot. Further, if one compares conditions at B (47° and 19% relative humidity) with condition G (41° and 60% relative humidity) then it is possible to affirm that in the first case there is no reason to fear rapid overheating while in the second case the endurance time is 1-2 hours at the most, although the temperature of conditions at G are lower than conditions at C even though temperature conditions at G are 6° lower than the condition at C.

Conditions at B are identical to conditions at A in thermal effect on man, although B is a lower temperature. If one notices the course of the lines limiting the thermal states, one will see that the equivalency of these conditions is relative since at low humidities the organism has more reserve capabilities than at higher humidities. Thus, temperature and humidity increase in the subclose layer of air which is observed, for instance, during physical work provides considerably less worsening of subjective evaluation in conditoins A than the same increase does in condition B (see the arrows pointing away from A and B in the graph).

The use of the graph will make possible a rapid almost obvious rough estimation or prediction of the subjective feeling of a worker and an approximate characterization of the degree of influence of external conditions on his capacity to work according to table 1.

It has turned out to be quite convenient to draw in on the graph data from the research in the microclimatic conditions of different objects of working environments, subclothing or sub - one piece clothing directly during the course of the experiment which has made it possible to accelerate the yield of a preliminary conclusion according to the experimental system. On the graph the dotted line represents the area of day and night temperatures which we found in some of the objects we studied. It is not difficult to see that a wordy description of the dynamics of these conditions would take up more space and lose sight of the obvious length with the subjective feeling of man. At the same time it is possible to say directly from the graph that at nighttime the microclimate in the object is characterized by acceptable and comfortable conditions with a slight surplus of humidity. But in the daytime, especially in the hottest time, people are in a state of discomfort of the second degree (zone IV).

However, the above basically concerns a method of evaluating human endurance in high temperatures. In low temperatures, due to the possibility of wide variation of thermal insulating means, closed and external climatic conditions are not so closely related with the subjective evaluation of man that they could be presented in the form of a similar simple graph.

In order to solve the problems of evaluation and prediction of thermal state of an organism of military specialist at different levels of physical dress and possible varients in clothing worn we compiled a summarized table 2 containing the initial data for a rough calculation of the thermal balance of the organism On the basis of the construction table we used a division of factors responsible for the increase and reductions of latent heat in the organism.

In section A (increase in latent heat) unified rounded-off data for an average man are given (weighing 65-70 kg with body area of 1.5-1.6 m^2) according to levels of endogenous formations of heat and exogenous thermal flow (points 5-7). In section B the limits are given for the variations in heat yielded depending on the physical indicators of the surrounding environment (points 1,2,7) physiological capabilities of the organism (points 3 and 6) and thermal insulation properties of clothing (point 5).

TABLE II

SUMMARIZED TABLE FOR THE ROUGH COMPUTATION OF THERMAL BALANCE IN MAN UNDER DIFFERENT CONDITIONS PERFORMING DIFFERENT TYPES OF ACTIVITIES AND WEARING CLOTHING

A. Increase in latent heat

Point	Concersion mechanism and flow of heat toward the body	Heat in kcal/hr	Factors effecting the dynamics of latent heat
1	Basis exchange; heat formation, associated by chemical processes supporting live functions	70 ± 10	Glandular activity level of internal secretion (mainly the thyroid gland)
2	Basic exchange and formation of heat at static muscle tension (standing & sitting)	90 ± 20	questions
3	Basic exchange and formation of heat when performing physical labor;		level of physical load such as:
	a) light	100-150	work of navigator or radio man in airplane, classroom studies, walking, riding in an automobile, motorcyling
	b) intermediate	150-250	work of a pilot, navigator, radioman; technician working on parts, piloting a plane; military drilling, walking 5 km an hr, question firing & cleaning weapons;
	c) heavy	250-500	work of an airplane technician when carrying & moving heavy objects, carrying a parachute, forced walking at 6-7km an hr;
	d) very heavy	500-700	running, fast walk on skies, carrying heavy weights, swimming, cross country work, boxing, hard sport activities
	e) record	1500	running, swimming, lifting weights (for records)
	f) for an eight hour work day (average)		Alternation of periods of work and rest, rhythm of work
	intermediate	140-185	same
	heavy	185-250	same
	very heavy	250-350	
4	Basic exchange and reflector protective increase of heat conversion under cooling (chemical thermal regulation):		
	a) cool (shivering)	110-150	insufficient clothing to preserve heat
	b) very cold, threatening life (violent shivering)	150-400	for example, when falling into cold water
5	Possible heat flow from the external environment in natural conditions:		
	a) from the sun	0-300	Position, type of clothing, color of the surface, wind
	b) from hot air	0-150 (in a scale from +35+ +45°)	Poroncity of clothing, its quality as a heat insulator, wind velocity.
6.	Flow of heat from walls by radiation		For every degree above +33°
7	Drinking a glass of hot tea (plate of soup)	5-6 (instantaneously)	temperature of water (data for temperature of a fluid at 60°);

RIGHT SIDE OF TABLE

B. Loss or Reduction of Heat Content

Point	Method of giving off heat to the external environment	Rate of giving off heat in kcal/hr	Basic conditions providing data for the level of heat yield; notes
1	Heat given off from surrounding air from the surface of the skin or clothing: a) in calm air b) wind 1 m/sec c) wind 2 m/sec d) wind 10 m/sec	 9 18 28 48	Difference of temperatures: for every 1 degree of temperature of difference between the temperature of the surface of the skin or clothing and air temperature (noted: to compute total heat yielded it is necessary to take points 2,3, & 4 into account).
2	Heat given off by radiation from the surface of the skin or clothing	7	Difference in temperatures: for every degree in temperature difference for the surface of the skin or clothing and the walls
3	Heat given off by evaporation		Difference in pressure, vapor and skin and in the surrounding air: clothes, wind
	a) constant minimum	20-25	This so-called imperceptible perspiration
	b) maximum in ordinary conditions	250	At rest and when working in the shade when there is no wind
	c) maximum with wind	350-450	With well ventilated wet clothing (when working)
4	Heat given off by light unexcited respiration	10-30	Temperature & humidity of the air increase proportional to the decrease in air temperature (Between +20 & -50) & when ventilation of the lungs increases above 25 l/m
5	Heat given off through clothing: a) light clothing (underwear, dress, undershirt) b) indoor clothing (1 clo)[1] c) fall clothing (2 clo) d) winter clothing (3 clo)	 12 9 5,5 3,7	Difference in temperatures, for every 1 degree of difference between the temperature of the surface of the body (33°) & the air temperature from surrounding objects (without taking wind & solar radiation into account)
	e) warmest clothing (6 clo)	1,5-18	When calculating general heat given off, add points 3 and 4.
	f) thick fur sleeping bag (11 clo)	0.5	
6	Heat given off from internal organs to the surface of the skin: a) when skin blood vessels are maximally expanded b) when skin blood vessels are maximally contracted c) at comfort	 42 12 17-22	Difference in temperatures of internal organs & skin; for every degree the temperature falls between the temperature of the internal organs and the skin.
7	Heat absorbed when drinking a glass water	4-5.5 instantaneously	

[1]Clo - is a conditional unit of thermal insulation of clothing, 0.18 $\frac{°Cm^2hr}{kcal}$ in physical units for thermal resistance.

In the notes short explanations are given about the character of each of the indicators and methods for imploying them in calculations. For complete use of the data in the table it is of course necessary to take into account general reductions of the theoretical basis for human heat exchange as given for example in articles by N.K. Vitte, P.I. Grumenev, Barton and Edholm and others. Some types of more accurate calculations are possible after temperature research with devices of walls, surfaces of clothing, etc. But in a number of cases, quite satisfactory data can be obtained also by means of calculating by logical schemes.

As an example, we might give the case where it is necessary to calculate for example, of how a pilot would feel who makes an emergency landing in winter at -40° if he is dressed in winter clothing.

From point 5 in subdivision B we can determine the heat given off through winter clothing (3.7 kcal/hr per 1°); the difference in temperature of the skin (+33°) and the external environment (-40°) is 73°, so that the total heat given off is 3.7 x 73 = 270 kcal/hr.

From section A of graph 3 we see that in order to increase the level of heat production to the indicated limit it is necessary for the pilot to perform heavy work. If he just sits around (point 2, section A) he will cool off and the deficite will reach 270 - 100 = 170 kcal/hr. When losing 170 kcal of heat, he is in the zone of discomfort of the second degree (see table 1, point 7), i.e., in an hour the pilot will freeze. The deficiency in progress cannot be stopped by chemical-thermal regulation (point 4a, section A). In order to preserve a balance of heat while in a state of rest the pilot would have to be given the very warmest of clothing (point 5e, section B) 1.5 x 73° - 110 kcal. However, as practice shows, such clothing is too bulky and disturbs or is highly inconvenient for the pilot when in flight, and a compromise is therefore unavoidable between protective and operational qualities of aviation clothing.

Similar examples could be given; it is possible to compute, for example, the limiting temperatures at whose limits the approximate equality of the inflow and outflow of heat would be felt. By using the data in table 1 point 7, it is possible to compute when the discomfort zones of the I, II, and III degrees start, etc.

Thus, the tables and graphs given here make possible to diagnose roughly within a wide temperature range the effects of the external environment on the thermal state of man. The limits we have suggested here for the degrees of discomfort are a recognized attempt to broaden the problems of hygeienic norms for military conditions, in so far as it has long been recognized that a general hygienic norms are not always technically perceptible and the limits of allowable deviations from them have not been provided by any means.

We consider it advisable to extend the familiar concepts of comfort and discomfort with subdivision of the latter into gradations to other factors of the external environment (noises, vibrations, content of certain substances in the air, etc.). The unification of a system of norms for military conditions will obviously facilitate a better understanding of the requirements of military medicine by the planning engineers of the various services and by the command of the commanding line units.